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Research Article

Effect of Various Pretreatments on Quality Attributes of Vacuum-Fried Shiitake Mushroom Chips

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The objective of this study is to investigate the effects of pretreatments on the quality of vacuum-fried shiitake mushroom slices. Four different pretreatments addressed in this study were (1) blanching as control, (2) blanching and osmotic dehydration with maltodextrin (MD) solution, (3) blanching, osmotic dehydration, and coating with sodium carboxymethyl cellulose (CMC), (4) blanching and osmotic dehydration, followed by freezing. All samples were pretreated and then fried in palm oil at 90°C with vacuum degree of −0.095 MPa for 30 min. The results showed that pretreatments significantly ($p < 0.05$) affected the moisture content, oil content, color, water activity (a_w), total phenolic content, and sensory evaluation of shiitake mushroom chips. The blanching, osmotic dehydration, and coating pretreatment could improve color and sensory evaluation and also minimize the oil uptake of fried chips, whereas this treatment caused the highest reduction of total phenolic contents. There were no significant ($p > 0.05$) differences of fried chip in the texture among the four different pretreatments. The a_w values of all the fried chips were less than 0.38, indicating that the products had a long shelf life. Therefore, the blanching, osmotic dehydration, and coating pretreatment before vacuum frying was the most suitable pretreatment for vacuum-fried shiitake mushroom chips.

1. Introduction

Shiitake mushroom is one of the most popular edible mushrooms in the market, which has been valued as a food and medicine for thousands of years in Asia, and China accounts for over 70% of the world's shiitake production [1]. Numerous studies have shown its medicinal attributes including antitumor and antimicrobial activities, improvement of liver function, reduction of cholesterol activity, decrease of blood pressure, and enhancement of the immune system against diseases [2]. However, fresh shiitake mushrooms are highly perishable and start deteriorating within a day after harvest, causing difficulties in their distribution and marketing as fresh products. It is well known that fried products have consumer appeal in all age groups and in virtually all cultures, the process is quick and can easily be made continuous for mass production, and the food appears sterile and dry, with a relatively long shelf life. Furthermore, vacuum frying is one of the latest optional methods applied to fruits and vegetables with low oil content and the desired texture and flavor characteristics [3]. This method processes the fruits and vegetables under pressures well below atmospheric levels, preferably below 8 kPa that can lower the boiling points of frying oil and moisture in food. Moisture can be thus removed from the fried food rapidly once the oil temperature reaches the boiling point of water. As a result, vacuum frying is a feasible option for processing of shiitake mushroom chips.

There were many previous researches focused on preserving nutrients and reducing oil content during the vacuum frying process [4–7]. In fact, some quality deteriorations could take place during the vacuum frying process. To improve the quality of vacuum-fried products, several pretreatments methods, such as blanching, predrying, osmotic pretreatment, coating, and freezing methods, have been applied to the frying of foods [8–12]. Blanching is a highly effective pretreatment method to improve the product quality of fried food; it brings a considerable improvement in the color of the vacuum-treated samples and less oil absorption [13]; it also could reduce the oil absorption by gelatinization of surface starch [14]. Pedreschi and Moyano have investigated the effect of predrying on texture and oil uptake of potato chips and found that predrying dramatically decreased the oil absorption and significantly increased the crispness of the potato slices after frying [15]. Osmotic dehydration pretreatment influences the quality of the final product by preventing discoloration [16]. Nunes and Moreira have reported that mango chips soaked in 65% maltodextrin (MD) solution resulted in a vacuum-fried product with the highest dehydration efficiency index (water loss/sugar gain), lowest oil content, and highest sensory scores [17]. Food hydrocolloids have been widely used as multifunctional additives in food processing to improve stability, modify the surface, and control the moisture content. It was shown that coating with 1% (m/v) pectin solution for bananas chips decreased the oil content in fried bananas chips by approximately 23% [18]. In addition, Sothornvit found that banana chips coated with guar gum maintained better quality and lower oil content after vacuum frying [19]. The hydrocolloid pretreatment provided more mechanical strength to the fruit tissue that could enhance sensory scores by improved structural integrity, while the difference in the behavior of color values of different chips upon hydrocolloid treatment might be related to the nature of the product, modification of surface property of the tissue, or differences in the frying process [20]. Freezing is an alternative pretreatment for increasing the rate of frying and improving the quality of fried products. During freezing pretreatment, the size of ice crystals was largely dependent on the freezing rate. Lower freezing rate resulted in the formation of larger ice crystals; large ice crystals may cause the mechanical damage, remarkable drip loss, and structural deformation of cellular structure of many biological materials [21].

Vacuum frying technology has been extensively investigated for lots of fruits and vegetables products [5–29]. However, to the best of our knowledge, there was no literature concerning the vacuum frying of shiitake mushroom (*Lentinus edodes*), especially for the effect of different pretreatments on physical-chemical properties of shiitake mushroom chips. Therefore, the objectives of this study were (1) to investigate the influence of different pretreatments (blanching, osmotic dehydration, coating, and freezing) prior to vacuum frying on the variations of moisture and oil content of the shiitake mushroom slices and (2) to evaluate the effect of pretreatments on the physicochemical properties of final vacuum-fried shiitake mushroom chips, such as texture, color, a_w, total phenolic content, and sensory evaluation.

2. Materials and Methods

2.1. Materials. Fresh shiitake mushrooms were purchased from local market in Lishui, Zhejiang, China, and kept in refrigerator at 4-5°C before frying. palm oil was supplied by the Jia-li Co. Ltd., Shanghai, China. The vacuum fryer equipped with a centrifuge (model VF2I, Hai Rui Company, Yantai, China) had a capacity of 100 L and a maximum temperature (the sandwich pot is heated by steam) and vacuum degree of 150°C and −0.096 MPa, respectively, for an oil capacity of 50 L. The vacuum frying equipment was shown in Figure 1. A Model WSC-S colorimeter (Shanghai Medical Appliance Factory, Shanghai, China) was used to measure the color of the samples. A texture analyzer (TA-XT2i, Stable Micro System Co. Ltd., Surrey, UK) was used for measurement of the breaking force of the samples. A a_w detector Ms-1 (NOVASINA Company, Switzerland) was used to measure the a_w of the samples. A Model SP-721E Visible Spectrometer (Shanghai Guanpu company, Shanghai, China) was used to measure the total phenolic content of the samples.

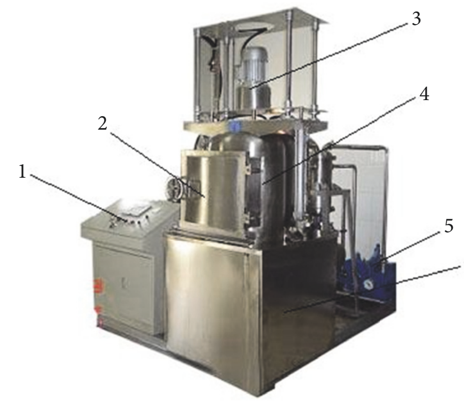

Figure 1: The vacuum frying equipment ((1) control center which controls the oil temperature, vacuum degree, frying time, deoiling speed, deoiling time, (2) the door of vacuum fryer, (3) frying basket lift and centrifugal deoiling machine, (4) frying chamber, (5) vacuum pump, (6) sandwich pot, storage oil, and steam heating).

2.2. Pretreatment of Shiitake Mushroom Slices. Fresh shiitake mushrooms were washed and then cut into 6 ± 0.5 mm slices after removing the stalks. The shiitake mushroom slices were treated as follows: blanching for 3 min in water (95°C), cooling under running tap water for 3 min, and draining on absorbent paper until the surface was nearly dry. The shiitake mushroom slices were divided into the following four different pretreatments: (1) blanched as control, (2) blanched and immersed in MD solution (50% w/v) at 25°C for 60 min, (3) blanched, immersed in the solution, and then immersed in a dilute CMC solution (0.5% w/v) at 25°C for 15 min, (4) blanched, immersed in the MD solution, and then freezed at −20°C for 12 h.

2.3. Vacuum Frying. A batch of 100 g shiitake mushroom slices, after the pretreatment, was fried in 50 L of palm oil. The oil temperature was 90 ± 2°C and vacuum degree was −0.095 MPa during frying (it is the best parameter based on our previous experiment). A centrifuging step (300 rpm for 2 min) before pressurizing the vessel after frying was added and its aim is to remove the excess surface oil. The moisture and oil content of the shiitake mushroom slices were measured at 0, 2, 4, 6, 8, 10, 15, 20, 25, and 30 min of frying. On the other hand, texture, color, a_w, and sensory evaluation were measured at 30 min of frying.

2.4. Analysis of Samples

2.4.1. Moisture Content. The shiitake mushroom chips were ground with a mortar at the end of each vacuum frying operation. Moisture content was determined using approximately 10 g of the ground shiitake mushroom chips and oven-dried at 102 ± 3°C until the weight stabilized [10]. The test was performed in triplicate.

2.4.2. Fat Content. The vacuum-fried shiitake mushroom chips were ground and oven-dried. Fat content of shiitake mushroom chips was determined by Soxhlet extraction with diethyl ether [30]. The test was performed in triplicate.

2.4.3. Color. The color parameters (L^*, a^*, b^*) of the shiitake mushroom chips were measured using a colorimeter Model WSC-S. The measuring aperture diameter was 10 mm, and the colorimeter was calibrated by a standard white board. Hunter L^* (lightness), a^* (redness/greenness), and b^* (yellowness/blueness) values were obtained from each color measurement. The samples were scanned at three different positions of the shiitake mushroom section, and the data were reported as average values of the three measurements.

2.4.4. Texture. Measurement of the texture of shiitake mushroom chips was carried out using a texture analyzer. Breaking force of the shiitake mushroom chips was performed at room temperature by a puncture test. The shiitake mushroom chips were placed over the end of a hollow cylinder. A stainless steel ball probe (P/0.25 s), moving at a speed of 5.0 mm/s over a distance of 5.0 mm, was used to break the chip. All numerical results were expressed in grams. The test was performed in triplicate.

2.4.5. a_w. The a_w of vacuum-fried shiitake mushroom chips was measured using a a_w detector Model MS-1 with a measurement range from 0.03 to 0.098 a_w. The test was performed in triplicate.

2.4.6. Total Phenolic. Total phenolics were determined using the Folin–Ciocalteu reagent [31]. Samples (2 g) were homogenized in 80% aqueous ethanol at room temperature and centrifuged in cold at 10,000 ×g for 15 min, and the supernatant was saved. The residue was reextracted twice with 80% ethanol and supernatants were pooled, put into evaporating dishes, and evaporated to dryness at room temperature. Residue was dissolved in 5 mL of distilled water. One-hundred microlitres of this extract was diluted to 3 mL with water, and 0.5 mL of Folin–Ciocalteu reagent was added. After 3 min, 2 mL of 20% of sodium carbonate was added and the contents were mixed thoroughly. The color was developed and absorbance measured at 650 nm by a spectrometer after 60 min using catechol as a standard. The results were expressed as mg catechol/100 g of dry weight material.

2.4.7. Sensory Evaluation. Fifty nonsmoking, self-confessed healthy panelists were trained to evaluate the quality of vacuum-fried shiitake mushroom chips in terms of appearance, color, flavor, texture, oiliness, and overall acceptability using a nine-point hedonic scale for likeness. The scores were assigned from extremely liked (9) to extremely disliked (1). Each sample was presented to the panelists for identification. Spring water was provided between samples for mouth rinsing by each panelist [29].

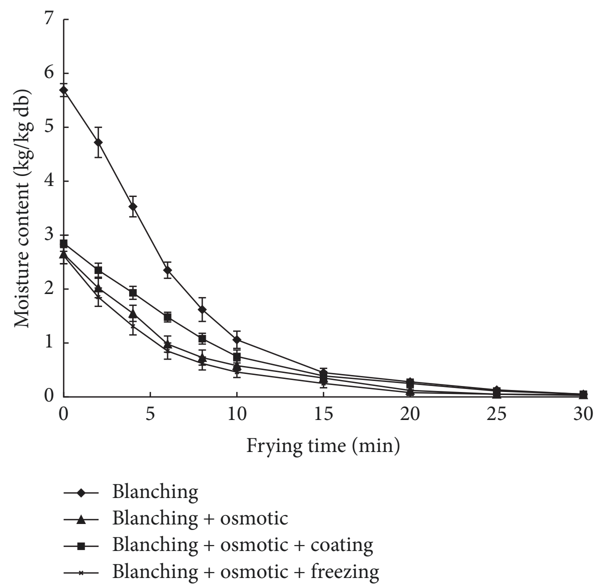

Figure 2: Effect of different pretreatments on moisture content of vacuum-fried shiitake mushroom chips.

2.5. Statistical Analysis. Data were analyzed by using the Statistical Analysis System (SAS, version 8.0, SAS Institute Inc., Cary, North Carolina). Analyses of variance were performed by the ANOVA procedure. Mean values were considered significantly different when $p < 0.05$.

3. Results and Discussion

3.1. Effects of Pretreatment on Moisture Content. The variation of moisture content during vacuum frying of shiitake mushroom chips with different pretreatments is shown in Figure 2. It can be seen that the initial moisture contents of shiitake mushroom slices were 5.69, 2.65, 2.85, and 2.62 kg/kg db, respectively. This could be attributed to the fact that MD osmotic treatment reduced the moisture content of materials, and after coating with CMC the moisture content was increased. The free water evaporated from the shiitake mushroom slices rapidly at the beginning of 10 min. The moisture contents of shiitake mushroom slices from high to low were blanching, osmotic, osmotic + freezing, and osmotic + coating during the frying process. The moisture content of blanching treatment was the highest because of its high initial moisture content. The moisture content of osmotic + freezing treatment was the lowest; this might be due to the fact that freezing could increase cell membrane penetrability of the material and cause the water to more easily evaporate [10]. The moisture content of blanching + osmotic + coating treatment was higher than the samples without coating. This is because CMC coating provided effective moisture retention

Table 1: The color value of shiitake mushroom chips for different pretreatments.

Pretreatment	L^*	a^*	b^*
Blanching	36.62 ± 0.36^{a}	5.37 ± 0.32^{c}	12.37 ± 0.28^{c}
Blanching + osmotic	41.23 ± 0.35^{c}	4.42 ± 0.42^{ab}	10.47 ± 0.56^{ab}
Blanching + osmotic + coating	45.21 ± 0.34^{d}	4.14 ± 0.21^{a}	9.85 ± 0.45^{a}
Blanching + osmotic + freezing	39.60 ± 0.85^{a}	4.76 ± 0.18^{b}	11.17 ± 0.98^{b}

Note. Means with different letters within a column are significantly different ($p < 0.05$) by Duncan's multiple range test.

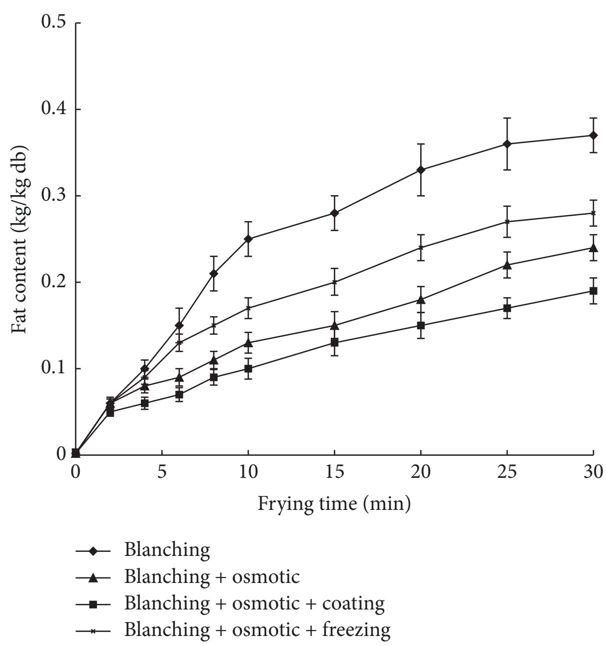

Figure 3: Effect of different pretreatments on oil content of vacuum-fried shiitake mushroom chips.

of the shiitake mushroom due to a strong interaction of hydrogen bonds between water molecules [32]. This is also consistent with the research of Maity et al. [20]. After 25 min, the moisture content in the products decreased slowly. When frying was finished, the moisture contents of four fried shiitake mushroom chips were 0.05 kg/kg db, 0.03 kg/kg db, 0.04 kg/kg db, and 0.05 kg/kg db, respectively.

3.2. Effects of Pretreatment on Oil Content. The variation of oil content during vacuum frying of shiitake mushroom chips with different pretreatments was shown in Figure 3. It can be observed that the rate of fat absorption increased with increasing vacuum frying time at the first 10 min, and the rate of oil absorption increased slowly after 25 min. This coincided with the period of time at which water evaporated from the shiitake mushroom slices at the fastest rate (Figure 2). The final oil content of the chips was 0.37, 0.24, 0.19, and 0.28 kg/kg db, respectively. Shiitake mushroom chips coated with the CMC exhibited a reduction in oil absorption with content of 0.19 kg/kg db. This result correlated with previous studies for CMC having the ability to form edible coatings to barrier lipids into chips [20, 29, 33]. Figure 3 shows that shiitake mushroom slices treated with osmotic and osmotic followed by freezing also could reduce the oil uptake compared to only blanched products. This might suggest that osmotic treatment significantly reduced the initial moisture content of samples, and high initial free moisture content resulted in high final oil content [34]. The fat content of shiitake mushroom chips treated with freezing was higher than that without freezing. This might be because freezing destroys the cell wall structure and induces greater disruption of the shiitake mushroom cells, making the fat more easily absorbed and retained during the vacuum frying [10].

3.3. Effects of Pretreatment on Color Value. The effects of pretreatments on the color of vacuum-fried shiitake mushroom chips can be seen in Table 1. In the present study, the color values of shiitake mushroom chips ranged from 36.62 to 45.21 (L^*), 4.14 to 5.37 (a^*), 9.85 to 12.37 (b^*). The statistical analysis showed that pretreatments significantly affected the color values of shiitake mushroom chips ($p < 0.05$). Maillard reaction which occurs between reducing sugars and protein sources and oil uptake affects the final color of the fried products [35]. The pretreatment for coating showed the least browning and oil uptake, so the L^* value was the highest and the a^* value and the b^* value were the lowest.

3.4. Effects of Pretreatment on a_w, Breaking Force and Total Phenolic. As shown in Table 2, pretreatment significantly affected the value of a_w of shiitake mushroom chips ($p < 0.05$). Osmotic treatment can increase the solid content of products and bind up more free water [36]. This made the value of a_w of shiitake mushroom chips treated with osmotic dehydration greatly decrease. Water activity is an important property that can be used to predict the stability and safety of food with respect to microbial growth, rates of deteriorative reactions, and chemical/physical properties. The limiting value of a_w for the growth of any microorganism is less than 0.6 [37]. In the present work, all the chips had a_w of less than 0.38, which indicated vacuum frying is a good method to maintain quality and prolong the shelf life of the products. Breaking force is an indicator of the extent of crispness of vacuum-fried chips, with lower breaking force corresponding with higher crispiness. There were no significant ($p > 0.05$) differences in breaking force of shiitake mushroom chips treated with different pretreatments.

Antioxidant activity correlated significantly and positively with total phenolic [38]. Table 2 shows that total phenolic contents in the shiitake mushroom chips by different pretreatments were 3.32 mg/100 g (db), 3.15 mg/100 g (db), and 3.41 mg/100 g (db), respectively, and they were lower than that of the control (4.32 mg/100 g (db)). Polyphenols

Table 2: Effects of pretreatments on a_w, breaking force, and total phenolic content of shiitake mushroom chips.

Pretreatments	a_w	Breaking force (g)	Total phenolic (mg/g, db)
Blanching	0.38 ± 0.02^b	975.9 ± 17.5^a	4.32 ± 0.11^c
Blanching + osmotic	0.25 ± 0.01^a	960.2 ± 22.9^a	3.32 ± 0.09^b
Blanching + osmotic + coating	0.25 ± 0.01^a	978.7 ± 14.9^a	3.15 ± 0.08^a
Blanching + osmotic + freezing	0.26 ± 0.01^a	980.5 ± 18.2^a	3.41 ± 0.08^b

Note. Means with different letters within a column are significantly different ($p < 0.05$) by Duncan's multiple range test.

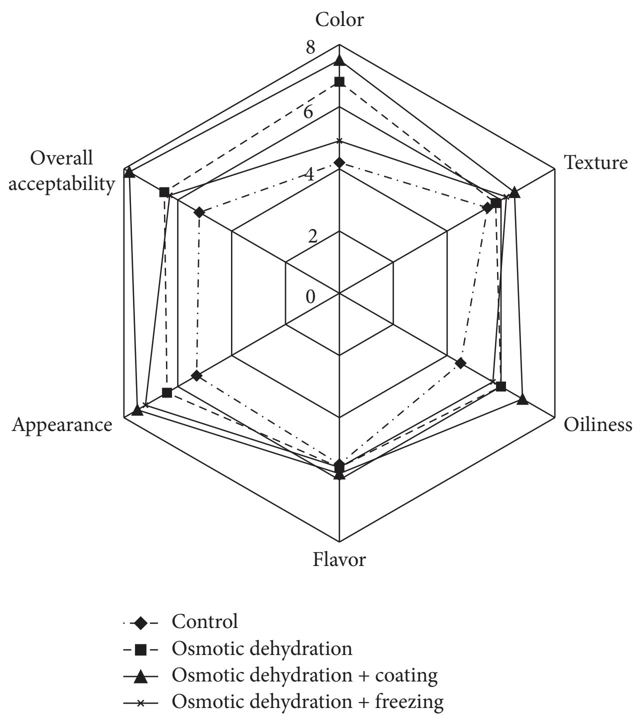

Figure 4: Sensory evaluation of the quality of vacuum-fried shiitake mushroom chips in four experimental conditions.

entered into water, when shiitake mushroom slices were dipped into MD and CMC solution, resulting in the reduction of content, while the control samples retained more total phenolic contents.

3.5. Effects of Pretreatment on Sensory Evaluation. A sensory analysis was performed to determine the consumer preference of vacuum-fried shiitake mushroom chips. Figure 4 showed that the panelists liked the products as indicated by overall acceptability scores. All groups received scores of over 4 on a 1–9 point hedonic scale. No significant ($p < 0.05$) differences were found in flavor or textures detected by the judges, since vacuum frying can preserve the natural flavor and keep crisp of shiitake mushroom chips. In addition, all panelists considered that the untreated shiitake mushroom chips were more oily, with worse appearance and color, compared to others. This indicates that the three pretreatments before vacuum frying could reduce the oil absorption, preserve the natural color, and reduce shrink. As can be seen from Figure 4, blanching, osmotic dehydration, and coating pretreatment had the highest values of appearance, color, flavor, texture, and overall acceptability, indicating that this pretreatment was the most suitable for vacuum-fried shiitake mushroom chips.

4. Conclusions

In the present study, the influence of different pretreatments (blanching, osmotic dehydration, coating, and freezing) prior to vacuum frying on the variations of moisture and oil content, as well as the quality attributes of the shiitake mushroom slices, was investigated. Results showed that the drying rate of blanching, osmotic dehydration, and freezing pretreatment was the highest. As the frying time increased, the oil content of vacuum-fried products increased. The products obtained from blanching, osmotic dehydration, and coating pretreatment had the lowest oil content. In addition, all the pretreatments can significantly ($p < 0.05$) improve the quality attributes, including the color, sensory evaluation. All the fried shiitake mushroom chips had extremely low a_w values. Furthermore, blanching, osmotic dehydration, and coating pretreatment had the highest values of appearance, color, flavor, texture, and overall acceptability. Therefore, the vacuum-fried shiitake mushroom slices from the blanching, osmotic dehydration, and coating pretreatment had the lowest oil uptake and best color property and sensory evaluation, indicating that it was the most suitable for vacuum-fried shiitake mushroom chips.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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